HiLASE cryogenically-cooled multi-slab amplifier prototype operating at 100J/10 Hz

A. Lucianetti

HiLASE Project, Institute of Physics AS CR, Prague, Czech Republic

VII HECDPSSL Conference, Lake Tahoe (CA), 12.9.2012

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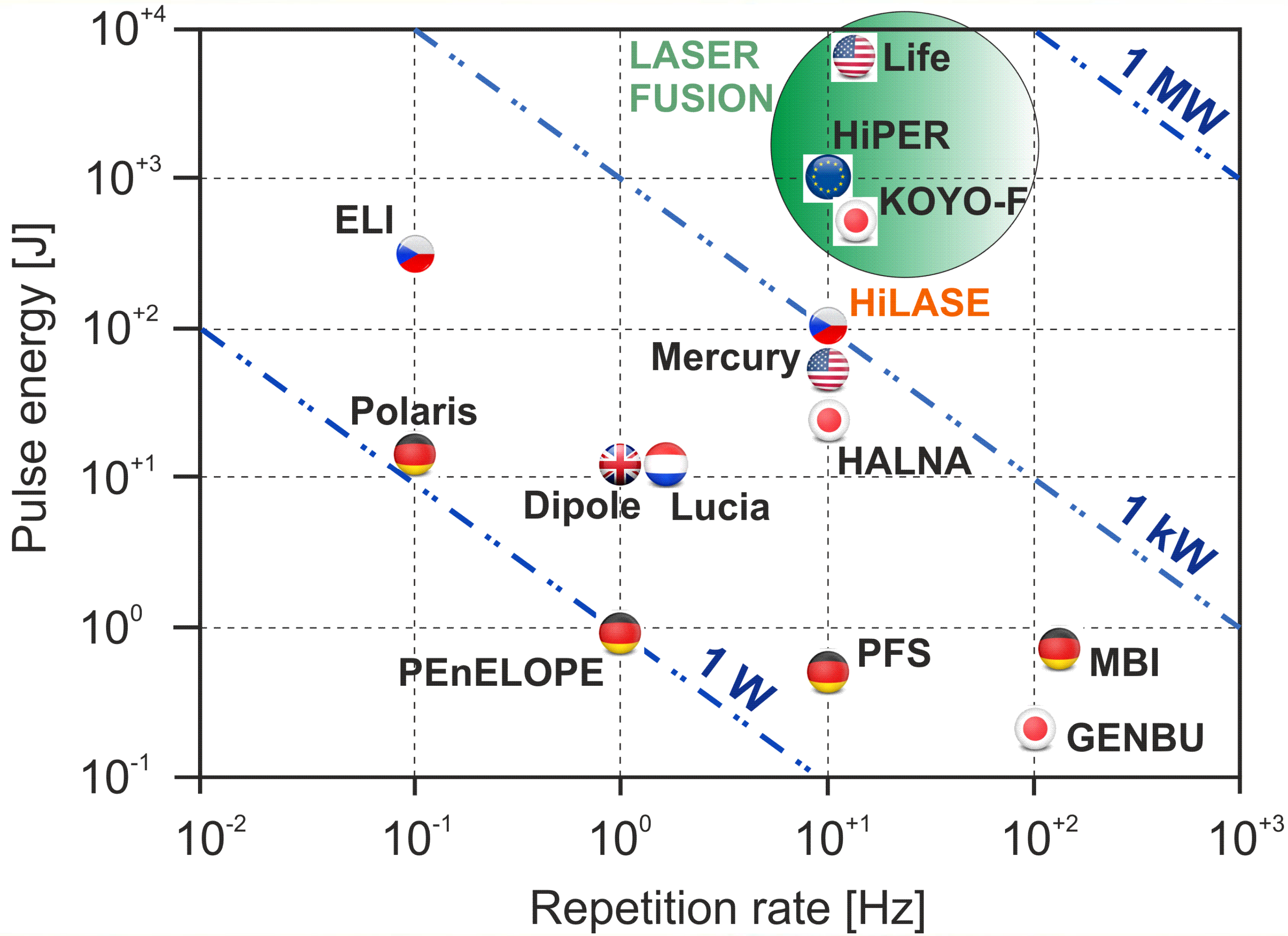
Current and future high-energy laser facilities



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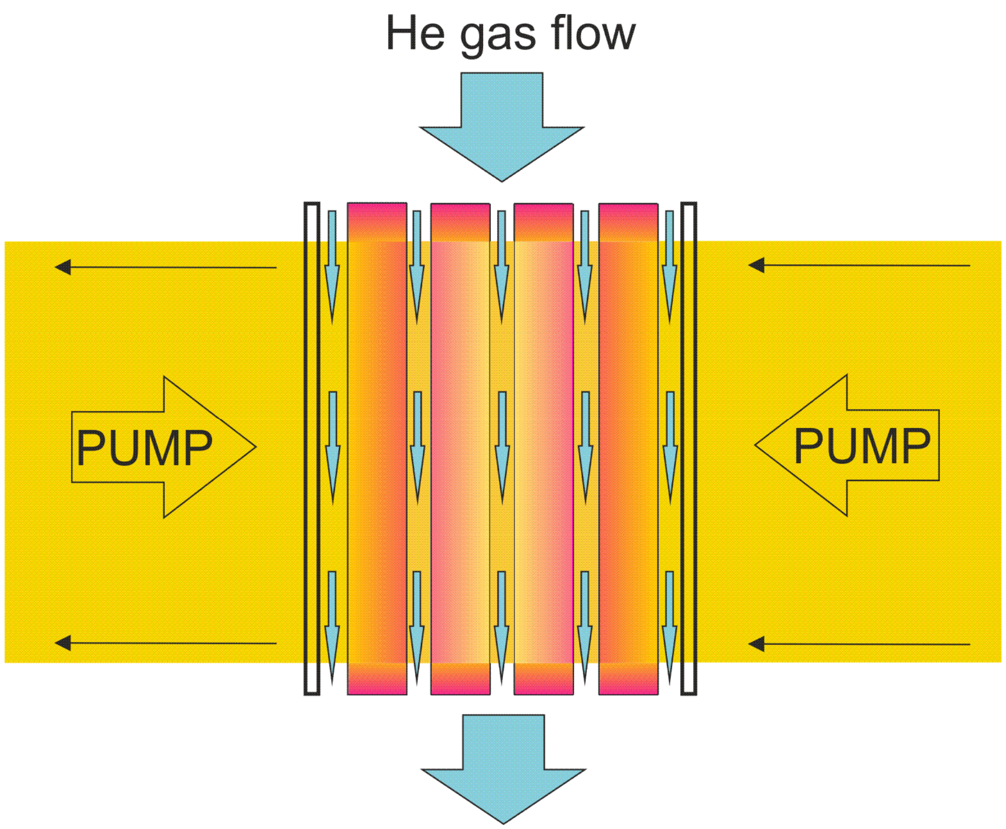
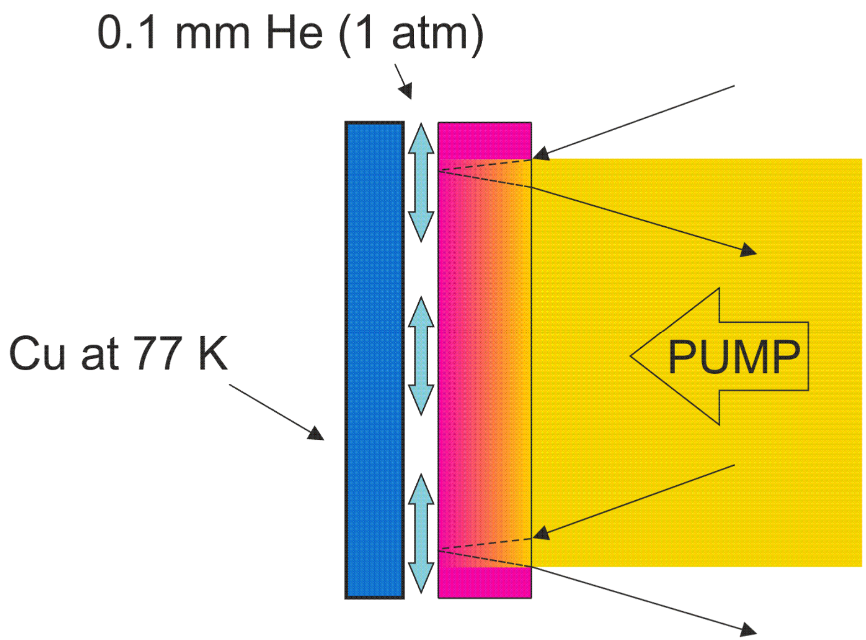
Cooling options for 100J-class lasers

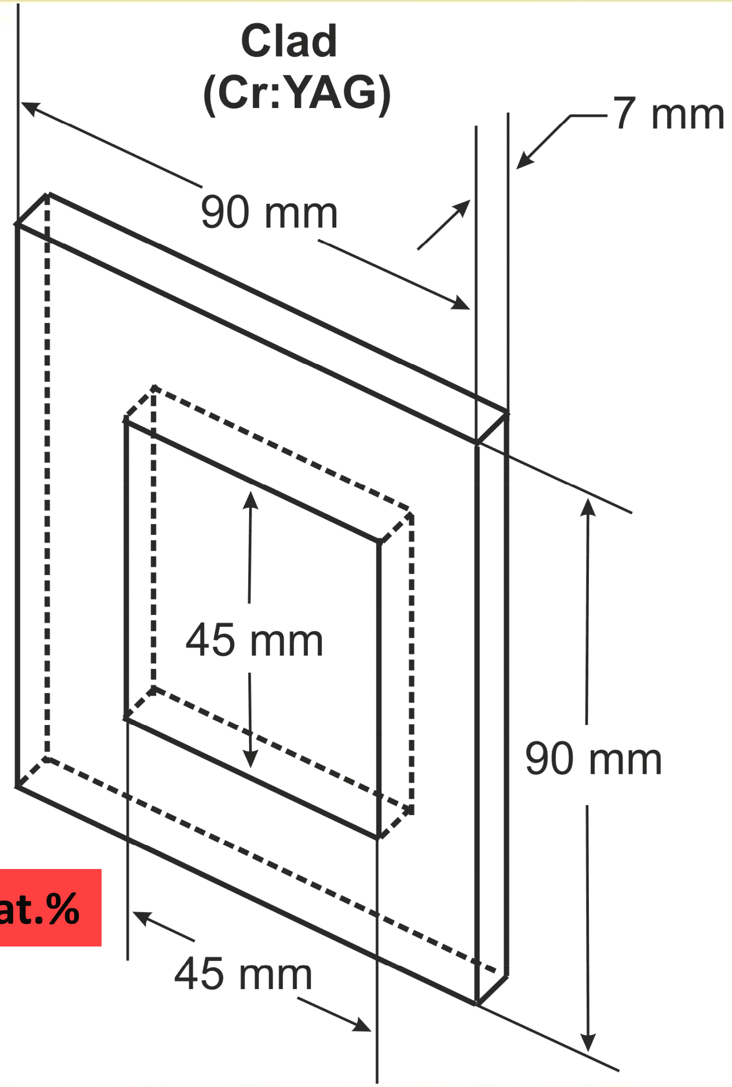
Multi-slab amplifier



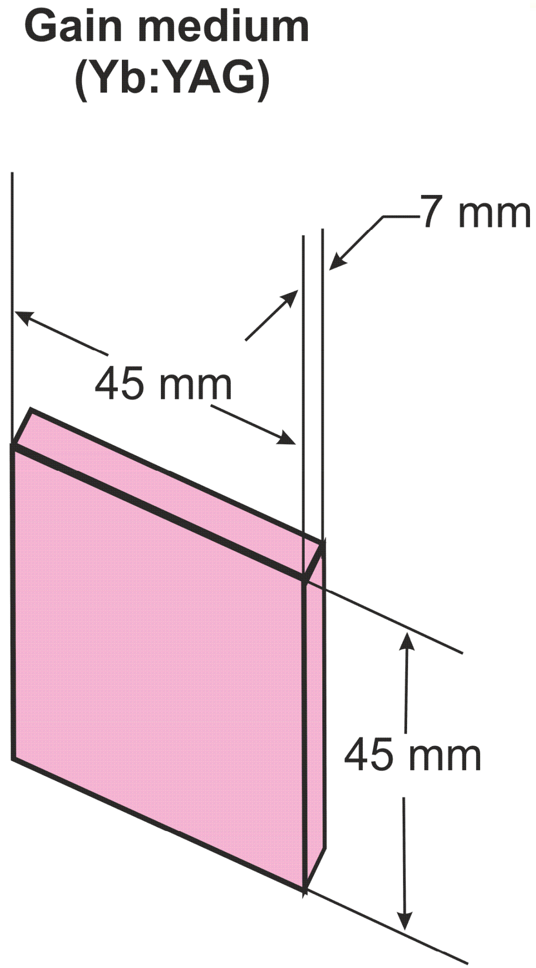
Active mirror amplifier



Cr:YAG clad optimization for HiLASE 100J



0.46 at.%



0.34 at.%
0.46 at.%
0.72 at.%
1.34 at.%

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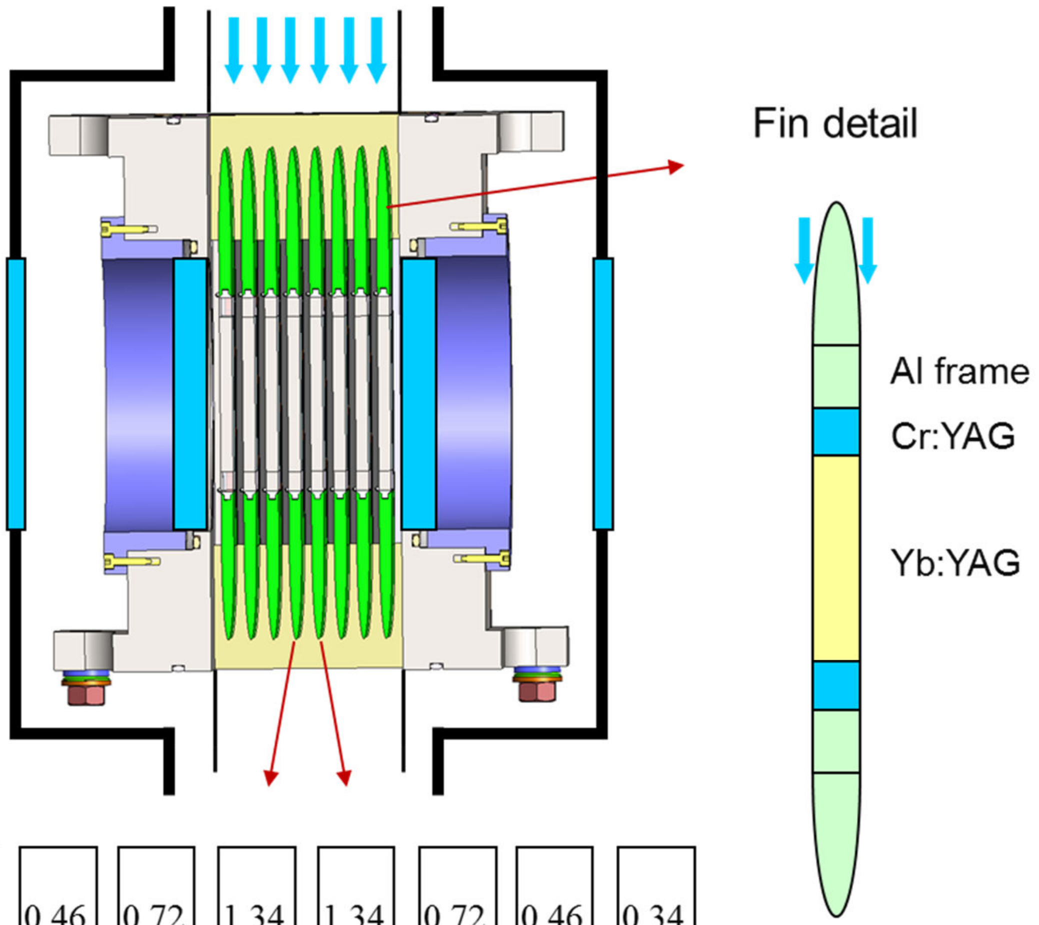
Amplifier head design

- 8 Aluminium fins housing the slabs
- Vacuum insulation of the cooled part
- Cooling with He gas
- Temperature ~ 150 K



Varied doping density
- average doping 0.74 at.%

0.34	0.46	0.72	1.34	1.34	0.72	0.46	0.34

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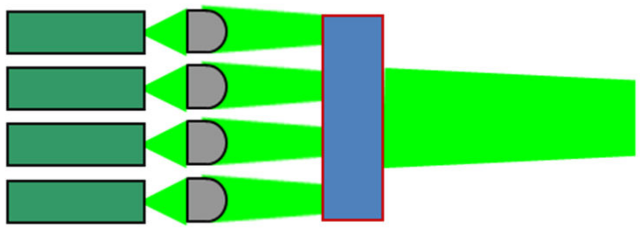
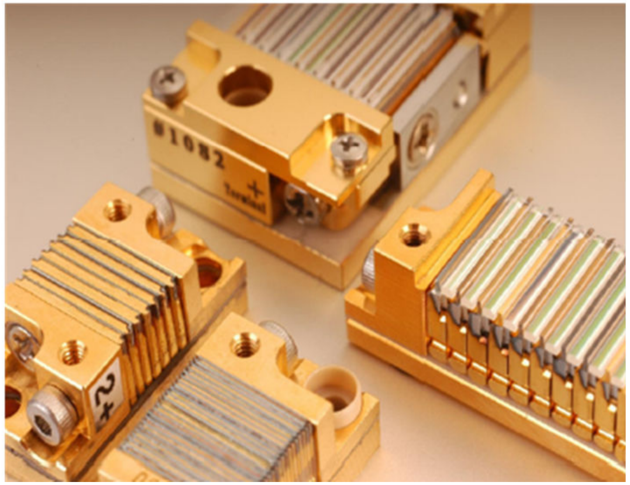
Pump laser diodes

Laser diode array parameters

• Wavelength	938 $\pm$ 2 nm
• FWHM	< 5-6 nm
• 95% energy	935-943 nm
• η	> 50%
• τ	0.8-1.2 ms
• f	10 Hz
• P_{tot}	400 kW
• Fast axis collimator	
• Lifetime	10^9 shots @ 10 Hz





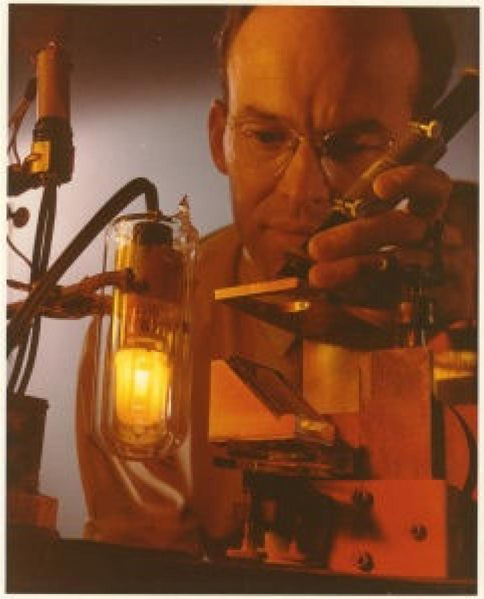
Insensitive to pump wavelength shift:
stored energy changed by 2% for 938 nm ± 3nm central wavelength or for bandwidth change between 3-6 nm FWHM

<u>*M. Sawicka et al. , JOSA B **29**, no. 6, 1270-1276 (2012)*</u>

Laser diode: 50th anniversary

hilase

Lasing in semiconductor diodes was first observed in 1962, only two years after the demonstration of a laser



Robert Hall at GE's Research Labs in Niskayuna, NY with the semiconductor (diode) laser around the time it was invented in early 1960s.

VOLUME 9, NUMBER 9 PHYSICAL REVIEW LETTERS NOVEMBER 1, 1962

COHERENT LIGHT EMISSION FROM GaAs JUNCTIONS

R. N. Hall, G. E. Fenner, J. D. Kingsley, T. J. Soltys, and R. O. Carlson
General Electric Research Laboratory, Schenectady, New York
(Received September 24, 1962)

Coherent infrared radiation has been observed from forward biased GaAs p-n junctions. Evidence for this behavior is based upon the sharply beamed radiation pattern of the emitted light, upon the observation of a threshold current beyond which the intensity of the beam increases abruptly, and upon the pronounced narrowing of the spectral distribution of this beam beyond threshold. The stimulated emission is believed to occur as the result of transitions between states of equal wave number in the conduction and valence bands.

Several requirements must be fulfilled[1] in order that such stimulated emission can be observed: (a) The electron and hole populations within the active region must be large enough that their quasi-Fermi levels are separated by an energy greater than that of the radiation; (b) losses due to absorption by other processes must be small relative to the gain produced by stimulated emission; and (c) the active region must be contained within a cavity having a resonance which falls in the spectral range within which stimulated emission is possible.

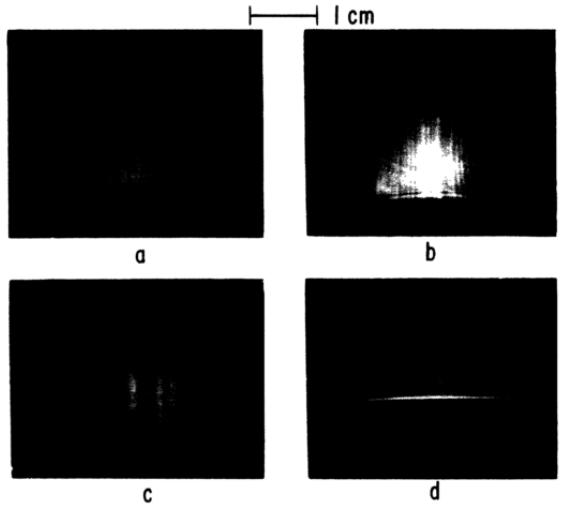
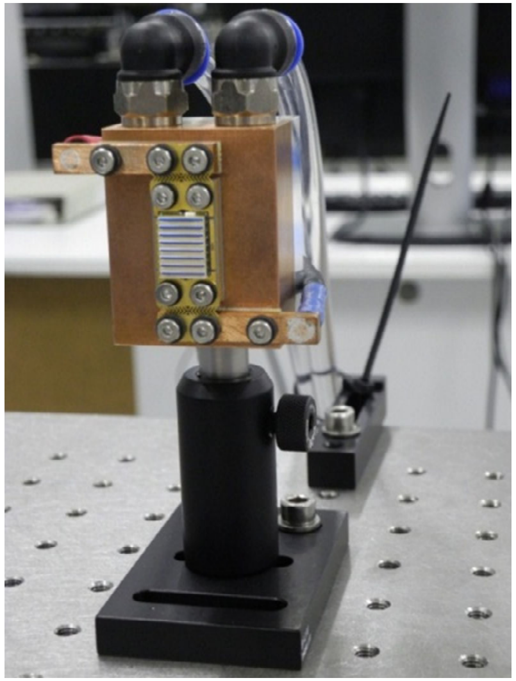


FIG. 1. Radiation patterns observed with image tube a distance d from junction. (a) and (b), diode L-69 below and above threshold, $d = 6$ cm. (c) Diode L-69 above threshold, $d = 15$ cm. (d) Diode L-75, $d = 5$ cm.

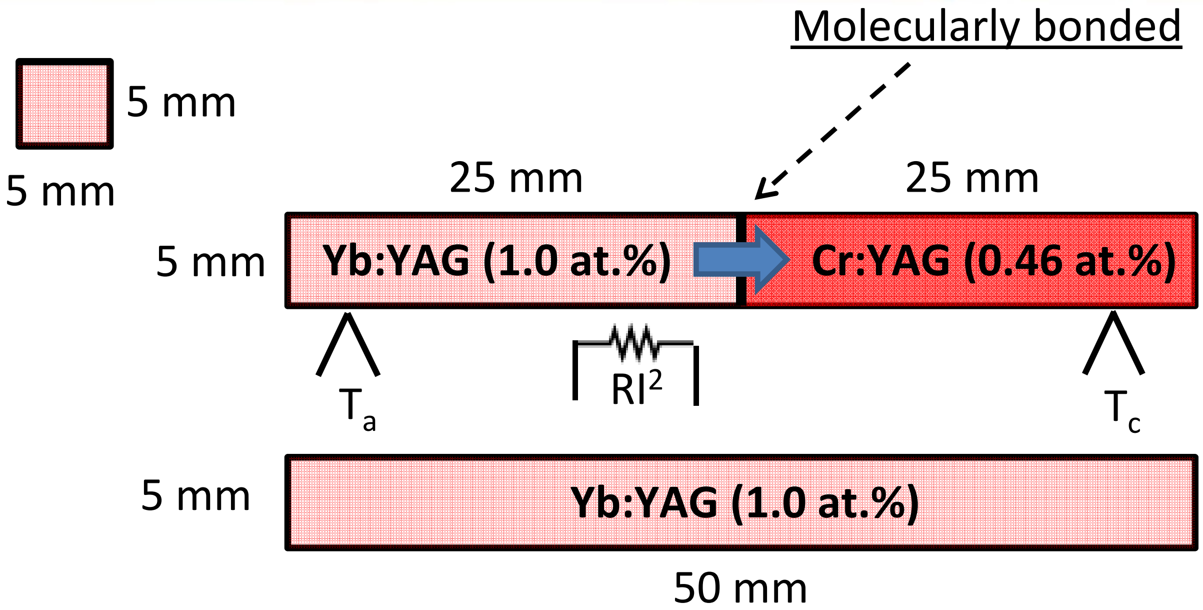
I) Test of laser-diode stacks from different vendors

HiLASE team is currently performing *in situ* investigations of laser-diode performance from various providers for their suitability to be used as pump sources in high repetition rate 2D arrays



- **Output power**
- **Spectrum**
- **Near field/far field**

2) Thermal resistance/optical quality measurements

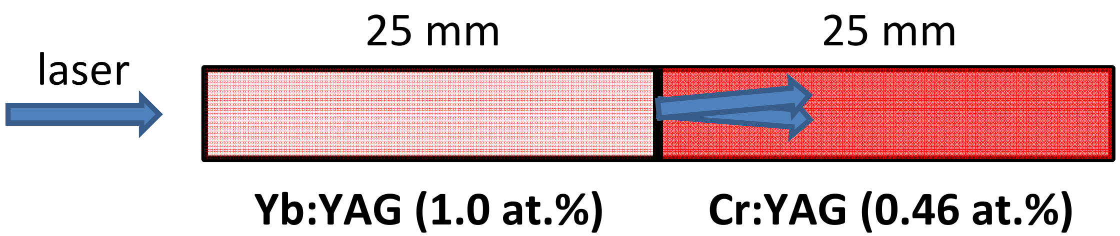


In collaboration with:

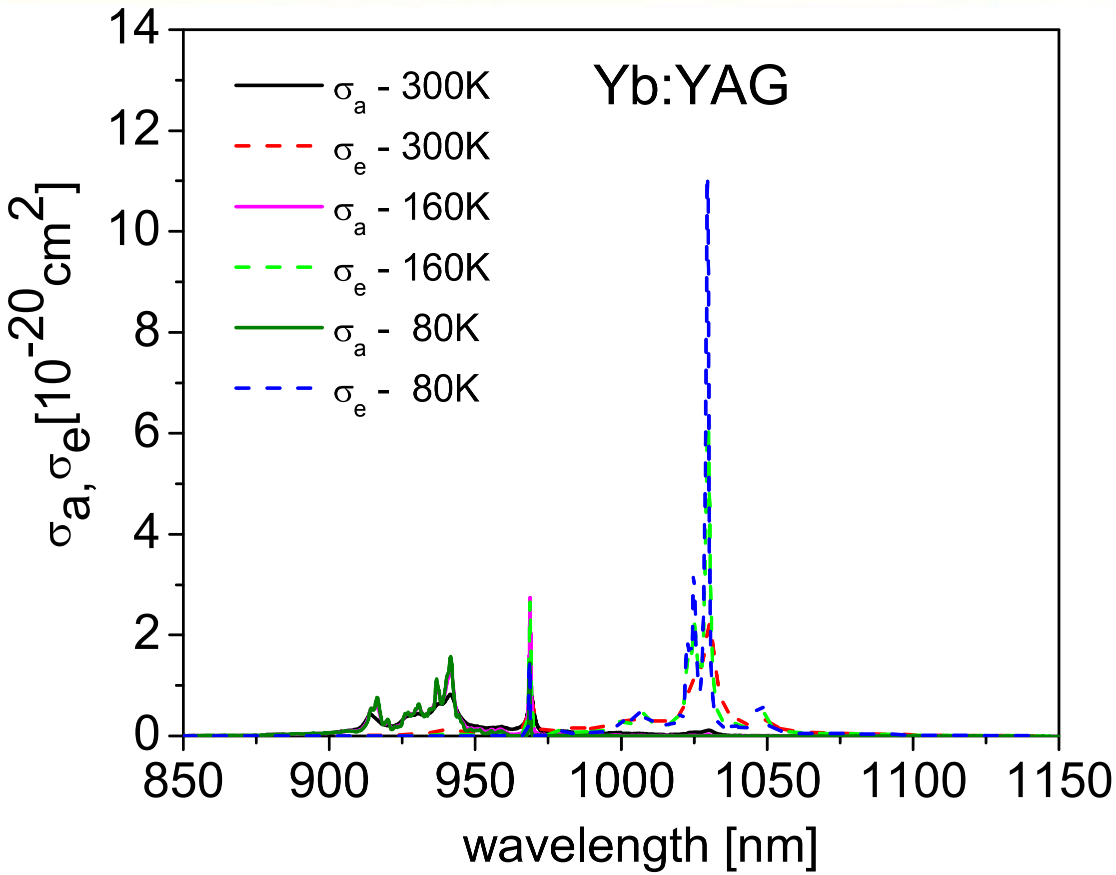
Crytur

CEA-Grenoble
CTU-Prague

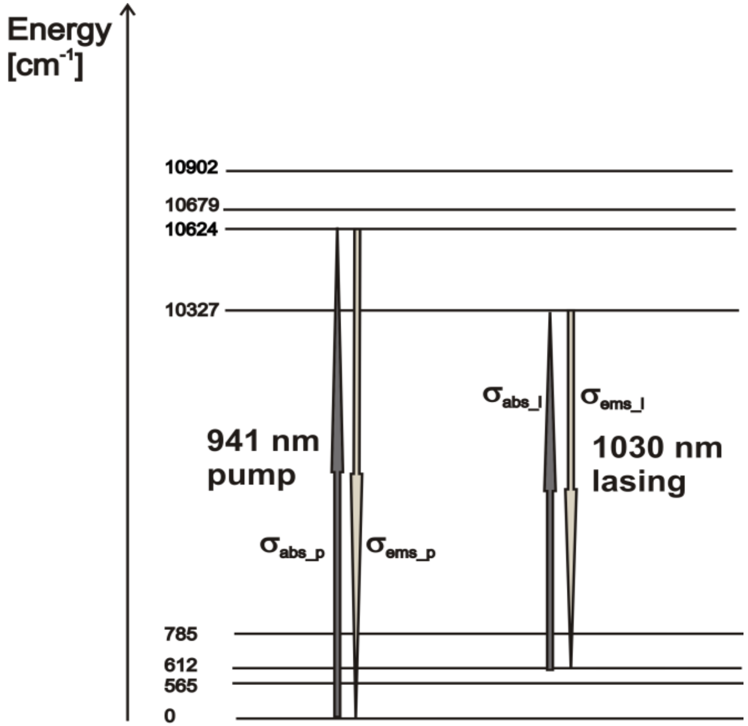
Reference sample
(same material)



3) Temperature dependent absorption and emission cross sections of Yb:YAG



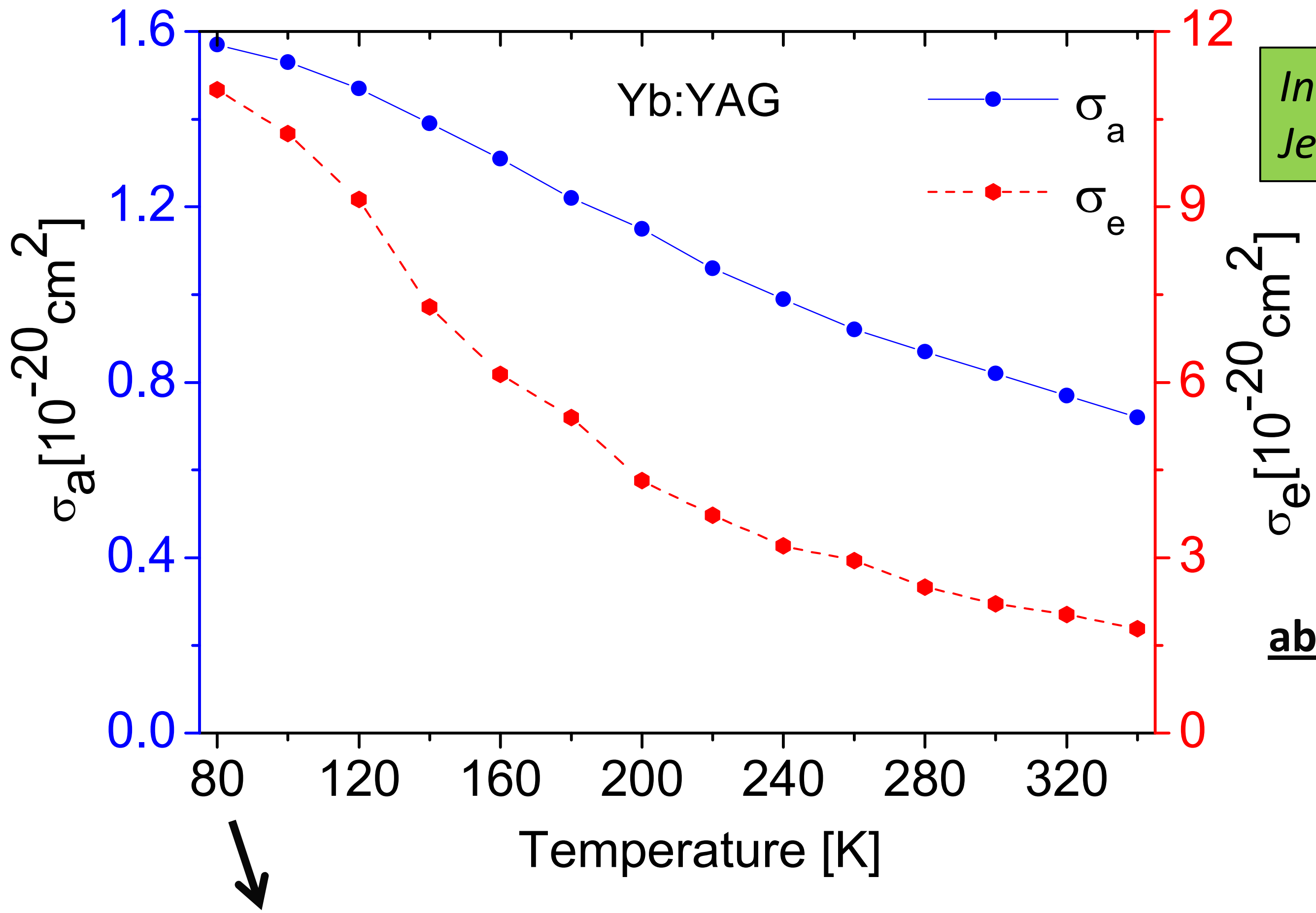
In collaboration with IOQ-Jena (J. Hein and J. Koerner)



Spectroscopic measurements allow to:

1) Verify the existence of impurities in Yb:YAG samples through search of 'anomalous' peaks
2) Record cross section profiles for energetics modeling of Yb:YAG amplifiers

3) Temperature dependent absorption and emission cross sections of Yb:YAG

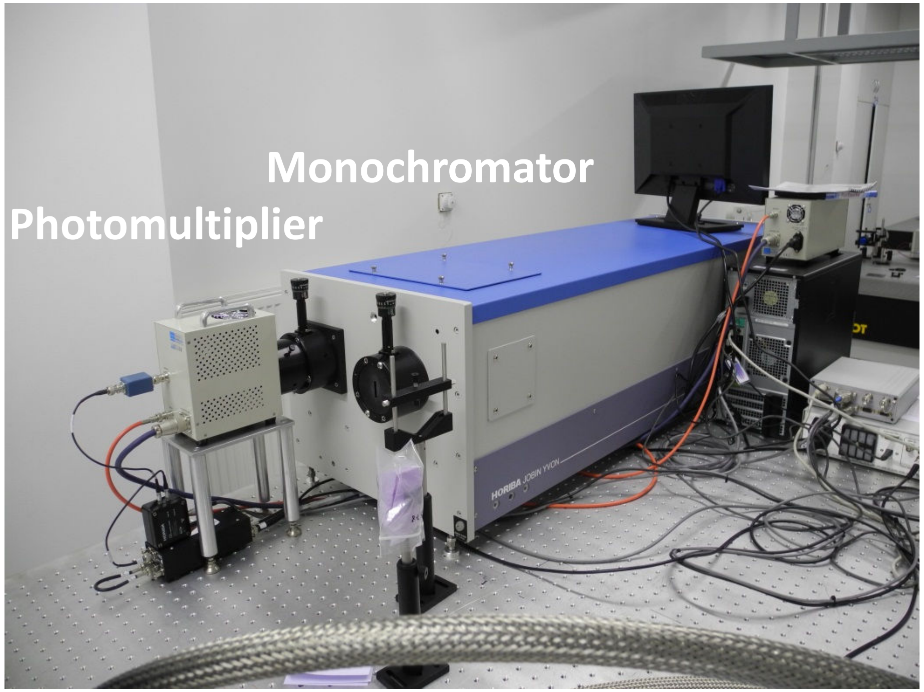


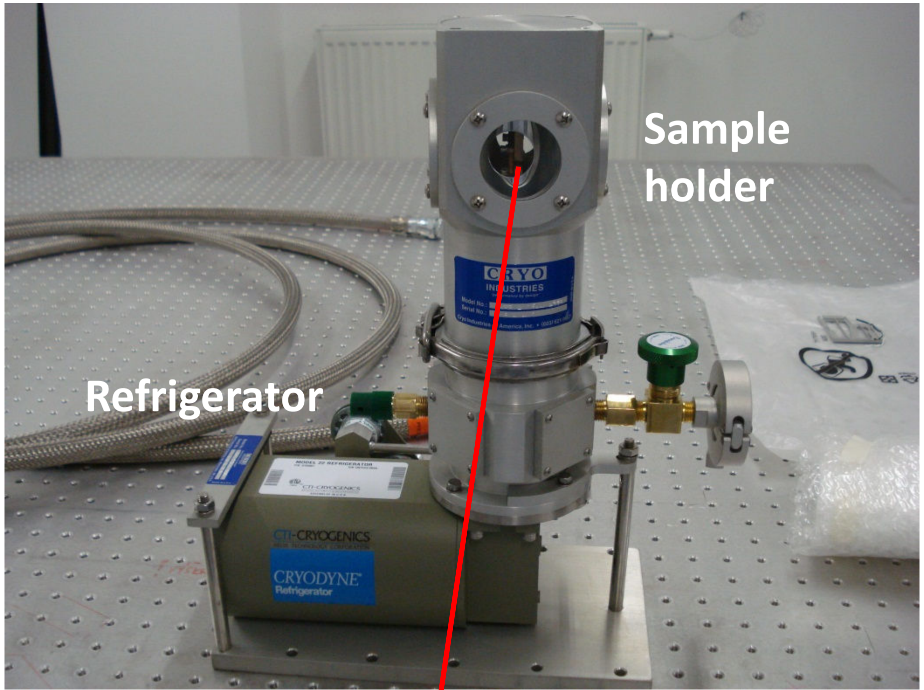
In collaboration with IOQ-Jena (J. Hein and J. Koerner)

abs = 941 nm, ems = 1030 nm

Liquid nitrogen is used to cool Yb:YAG samples down to 80 K

High resolution spectrometer at IoP



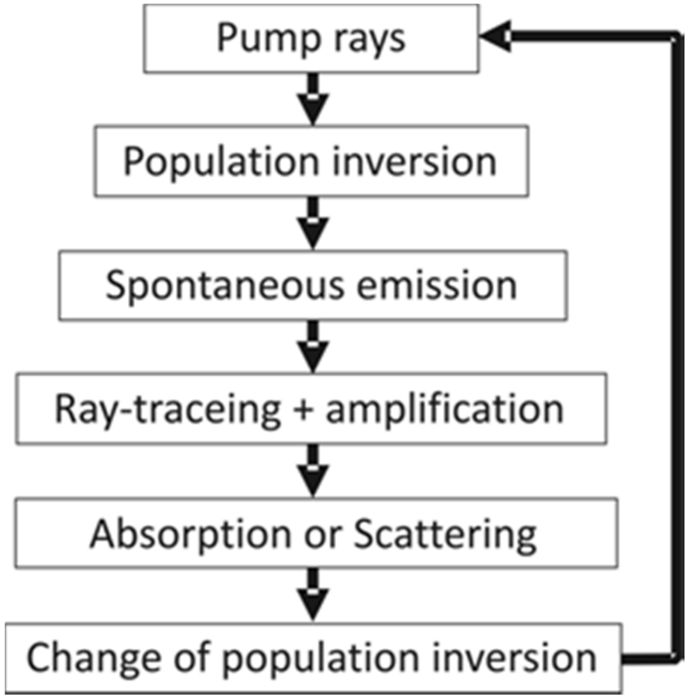


HORIBA (Yobin Yvon) spectrophotometer:
- Scanning spectrograph
- PMT image sensor
- Resolution: 6 pm@1100 nm

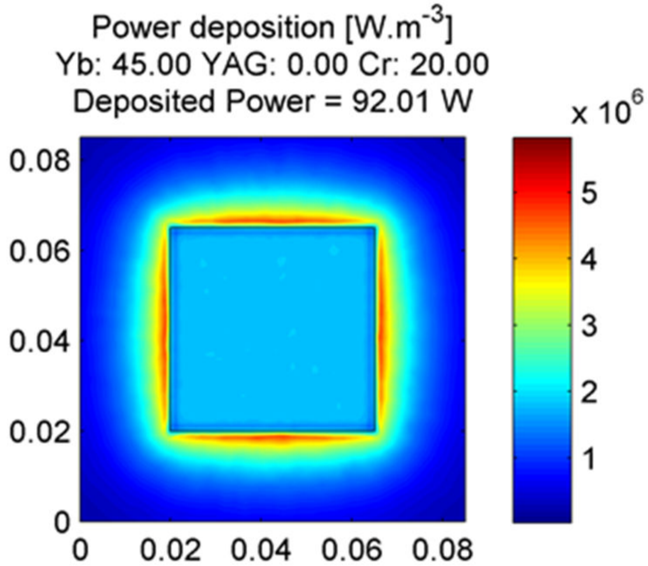
He cooling down to < 10 K will allow to determine the energy level splitting of Yb^{3+}

Heat deposition in HiLASE slab amplifiers

Flow chart of the 3D model (Magda's presentation)



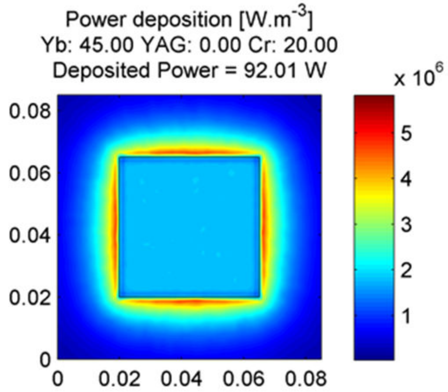
*M. Sawicka et al. , JOSA B **29**, no. 6, 1270-1276 (2012).*

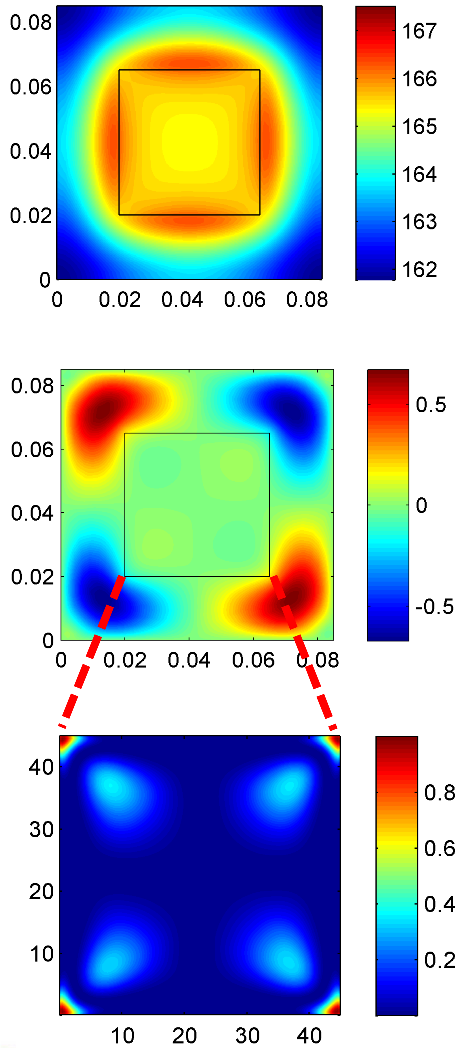


Output of the model:

√ Stored energy
√ Amplified Spontaneous Emission
√ Heat deposition

Thermal analysis of HiLASE slab amplifiers





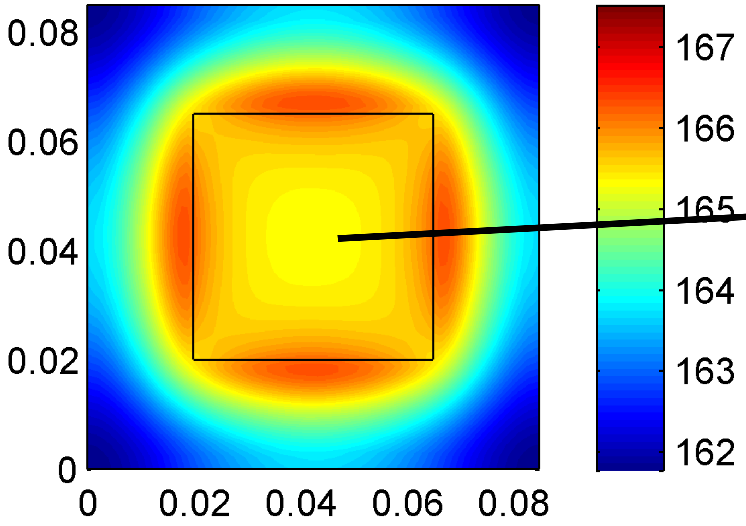
Temperature [K]

Stress-strain [MPa]

Depolarization loss (after 64 passes)

Paper being submitted to PRA

Temperature distribution in HiLASE amplifiers



Result of thermal modelling:

- **Maximum surface ΔT < 0.9 K in the pumped area**
- **Maximum volume ΔT < 1 K in the gain medium**

$$\boxed{OPD(x,y) = \int_0^l \frac{\partial n}{\partial T} T(x,y)dz + n_0 \Delta u(x,y) + \sum_{i,j=1}^{3} \int_0^l \frac{\partial n}{\partial \varepsilon_{i,j}} \varepsilon_{i,j}(x,y)dz}$$

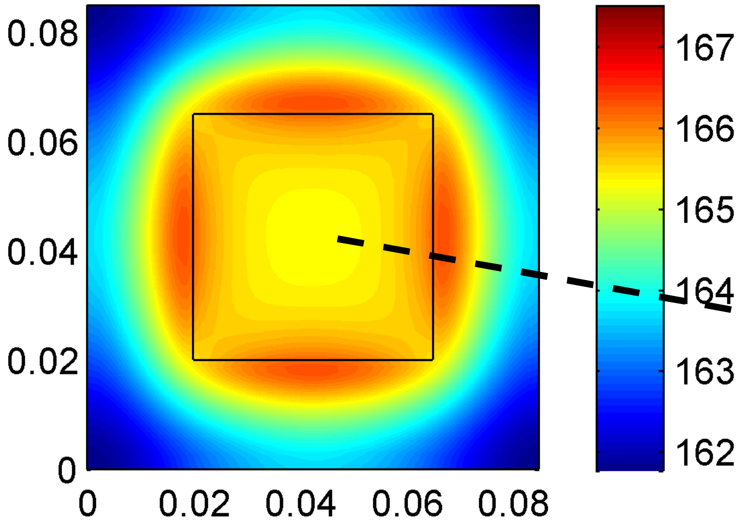
Contributions due to **temperature dependent**

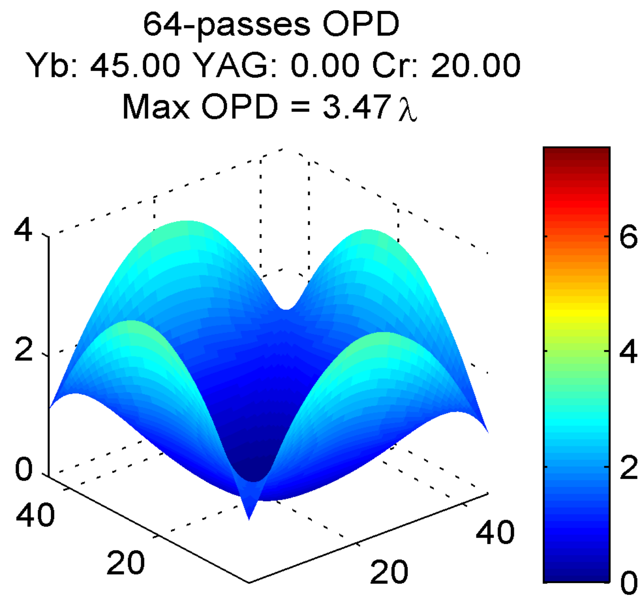
index change

deformation

Strain-induced birefringence

Temperature distribution in HiLASE amplifiers





4 passes through two heads

(8 Yb:YAG slabs + 9 He gaps)

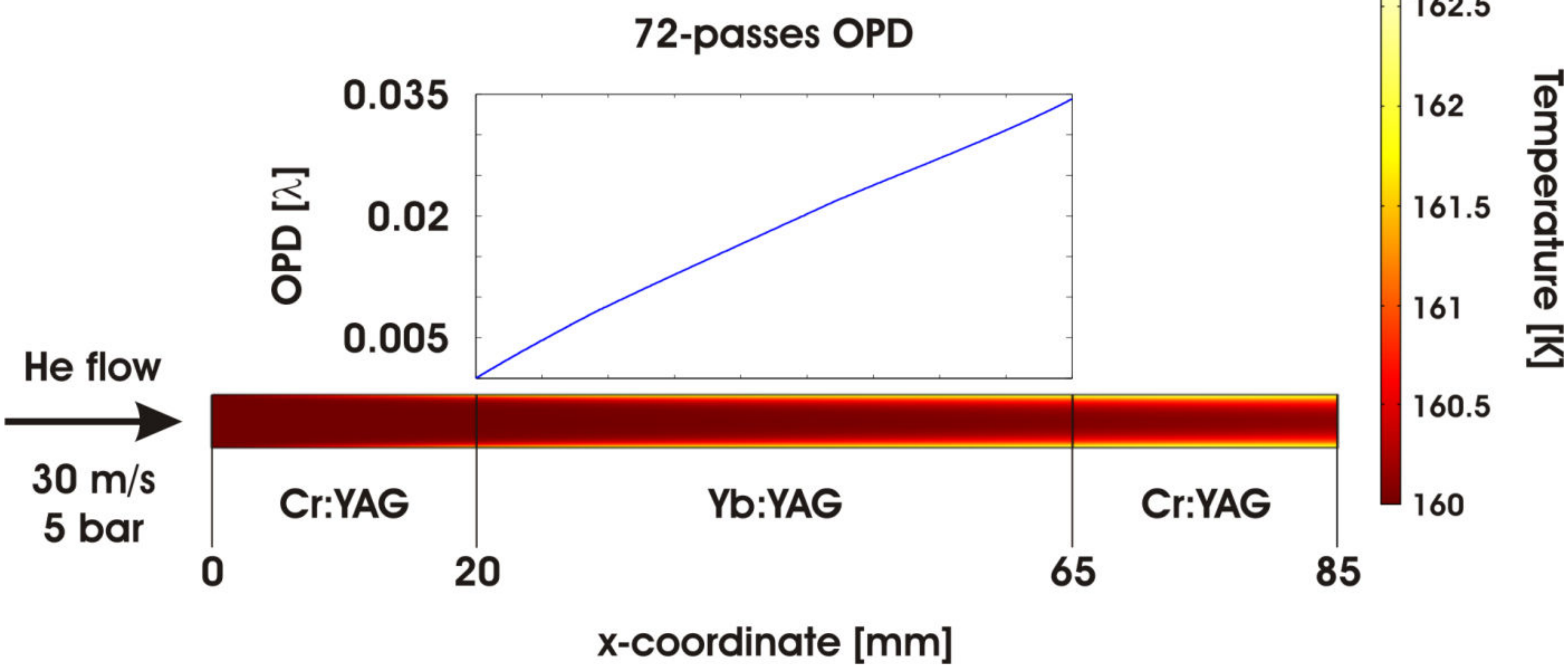
⇩

OPD < 3.5 λ(P-V)

Less than 1.5 λ after optimization

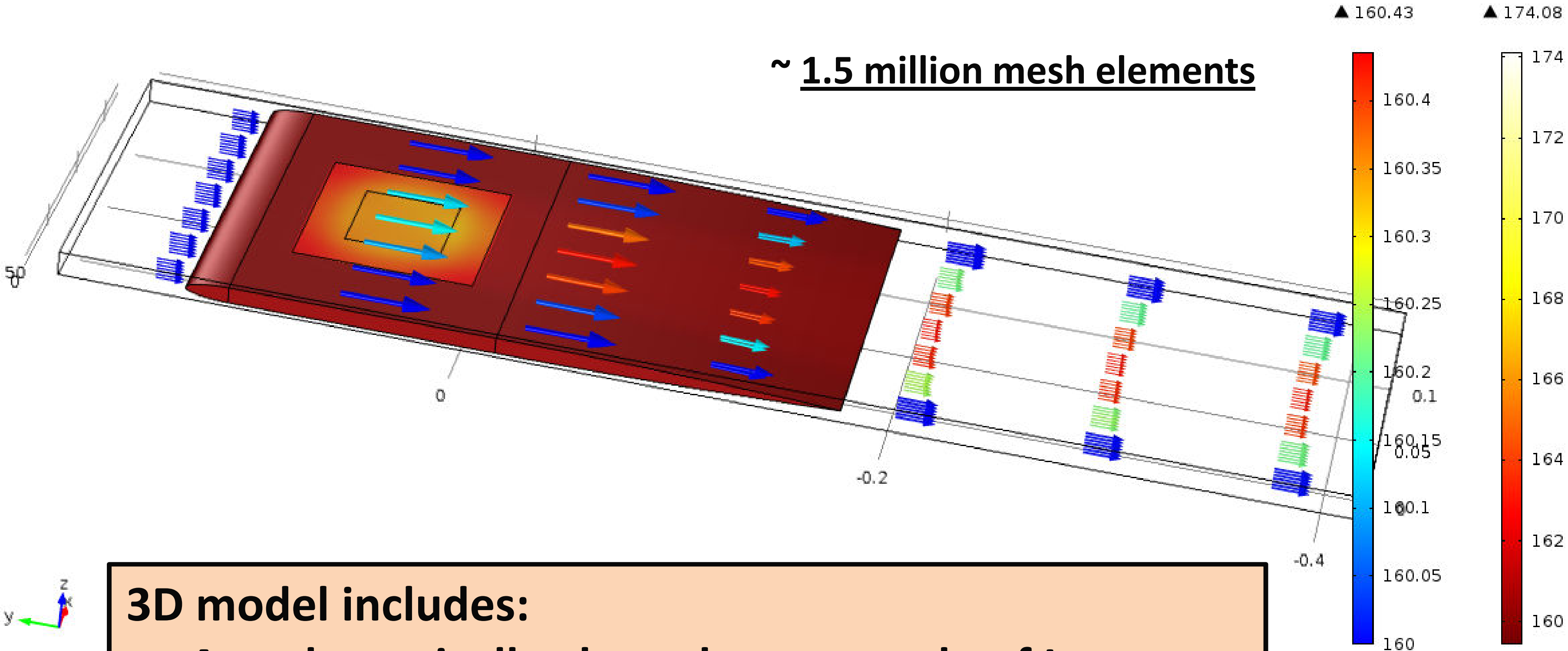
Wavefront aberrations in HiLASE amplifiers

OPD = ∑ (n(He)-1)*dL **40 slices**



<u>Contribution of OPD due to nine 4-mm Helium gaps is 0.035 λ</u>

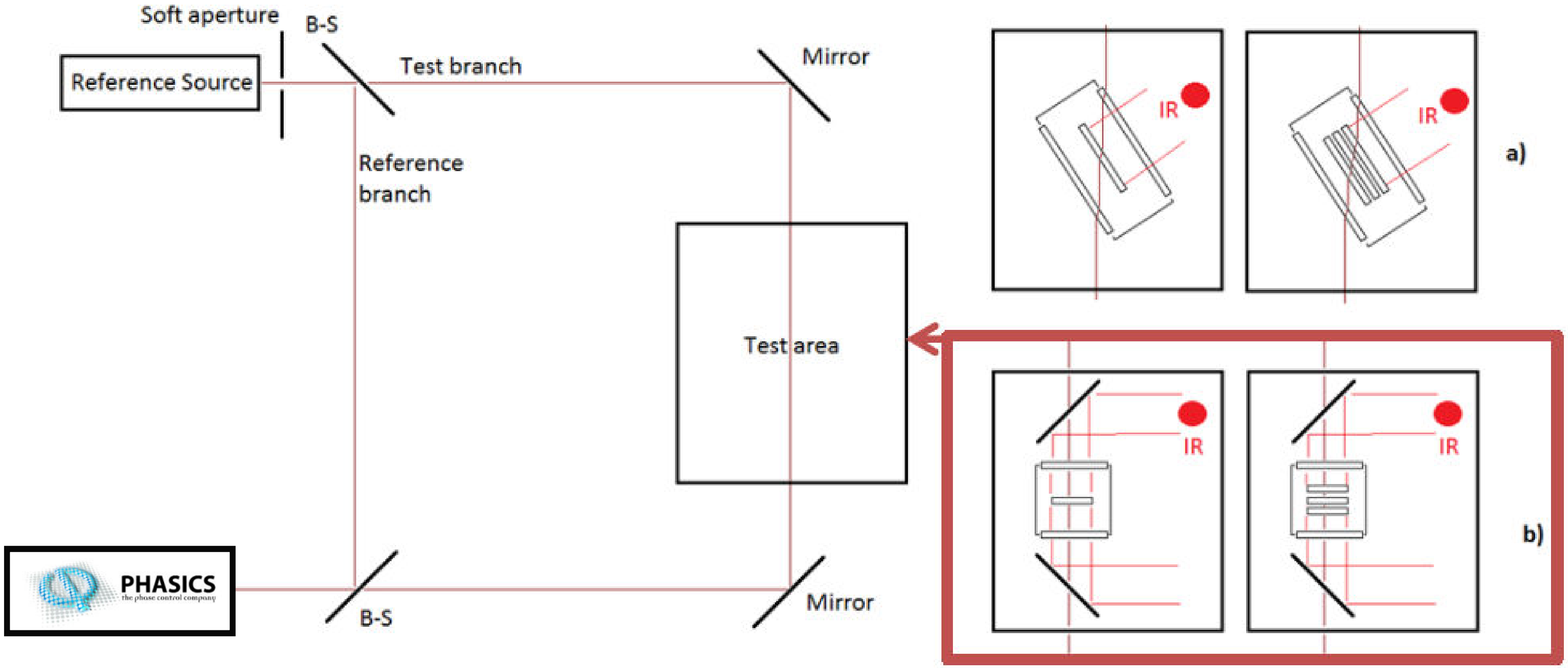
Wavefront aberrations in HiLASE amplifiers



3D model includes:

- Aerodynamically-shaped vanes made of Invar
- He gas flow at 160 K
- Optical surfaces – lambda/10 quality (in progress)

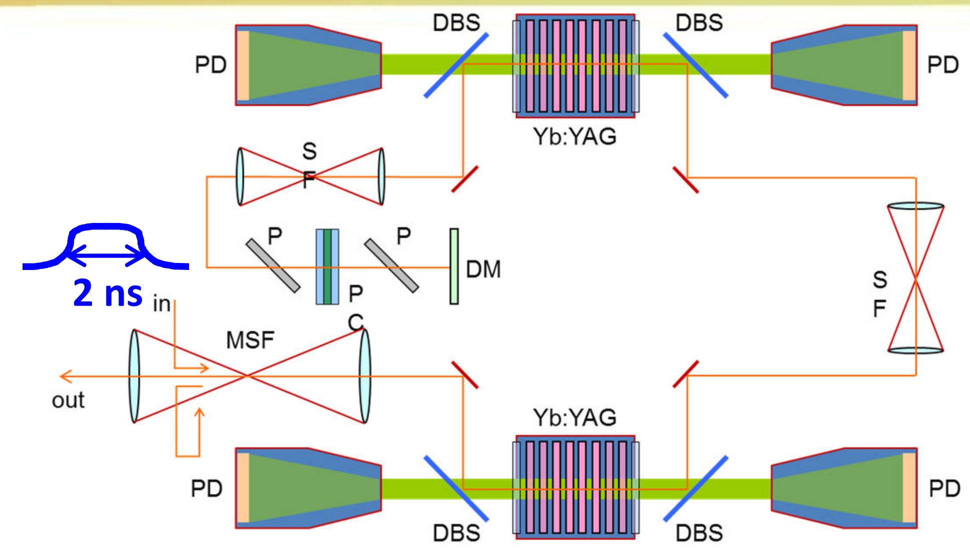
Wavefront aberrations in HiLASE amplifiers



- Halogen light bulb will deform the rectangular glass slabs (test area). Generated heat will reproduce the wavefront distortions expected in the 10 J laser;

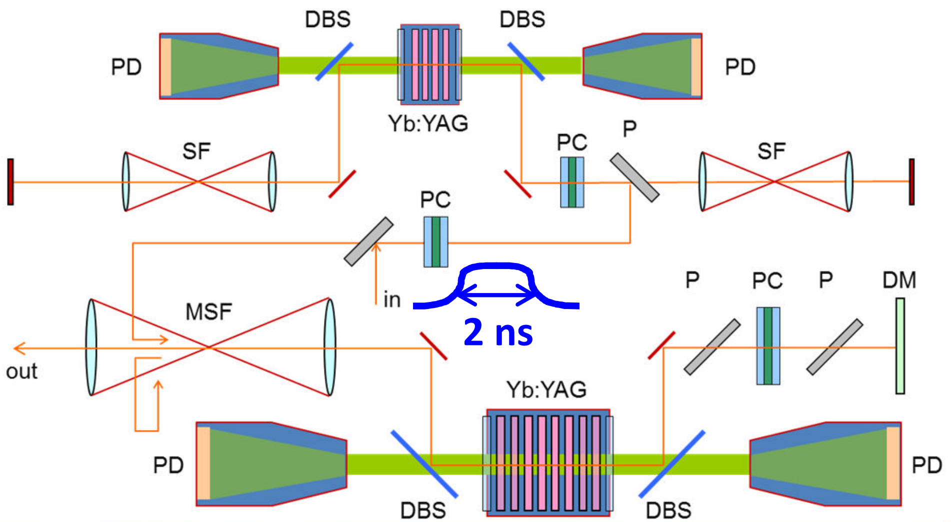
- Closed-loop AO system with a DM mirror will be tested soon in our laboratory

Optical layout of HiLASE power amplifiers



Two amplifier heads 100 J system

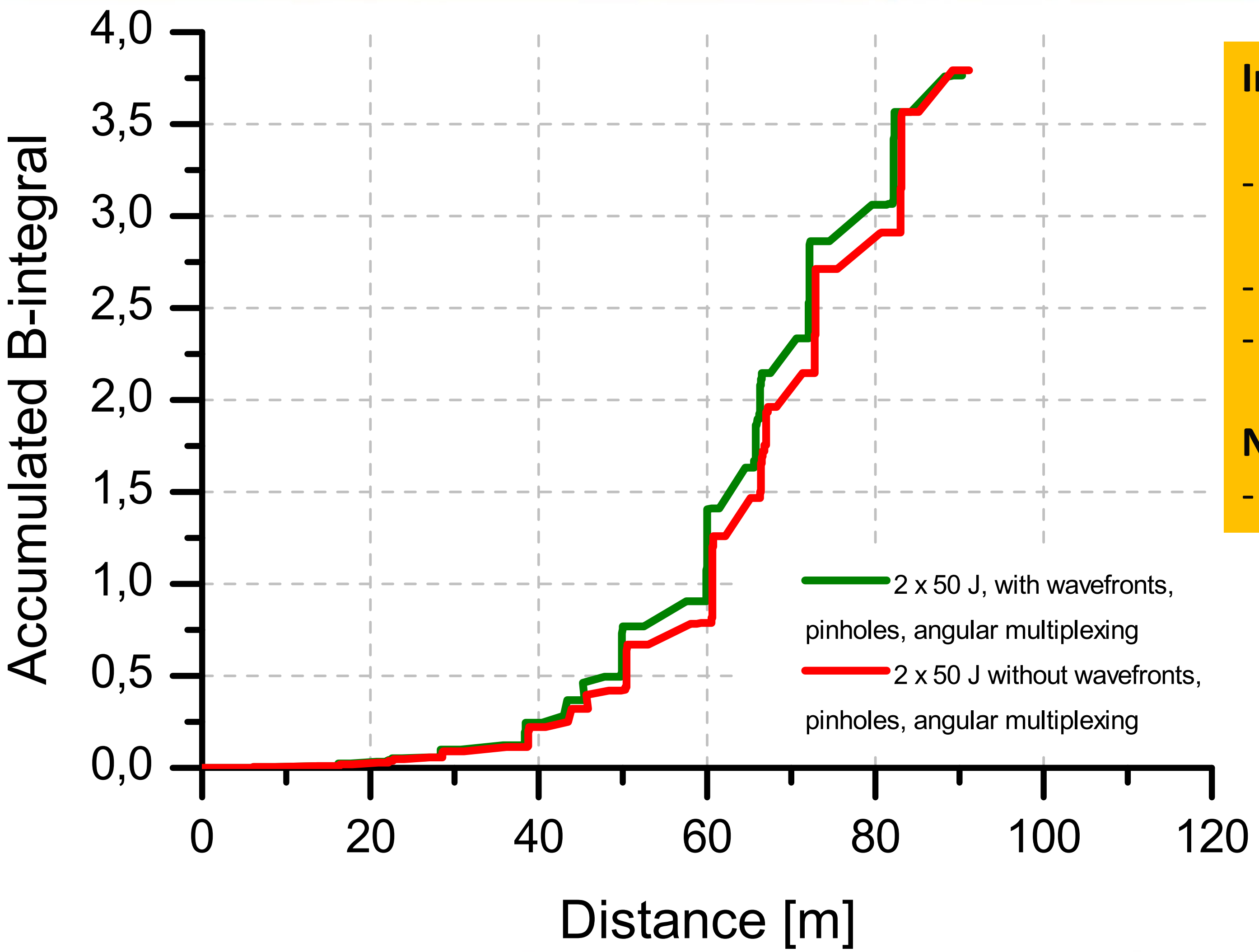
Peak pump power/head: 2 x 5 kW/cm²
Slab size: 45 mm x 45 mm



10 J + one amplifier head 100 J system

Peak pump power/head: 2 x 5 kW/cm²
Slab size: 20 mm x 20 mm (10J) +
60 mm x 60 mm (100J)

Accumulated B-integral in dual head 100 J laser



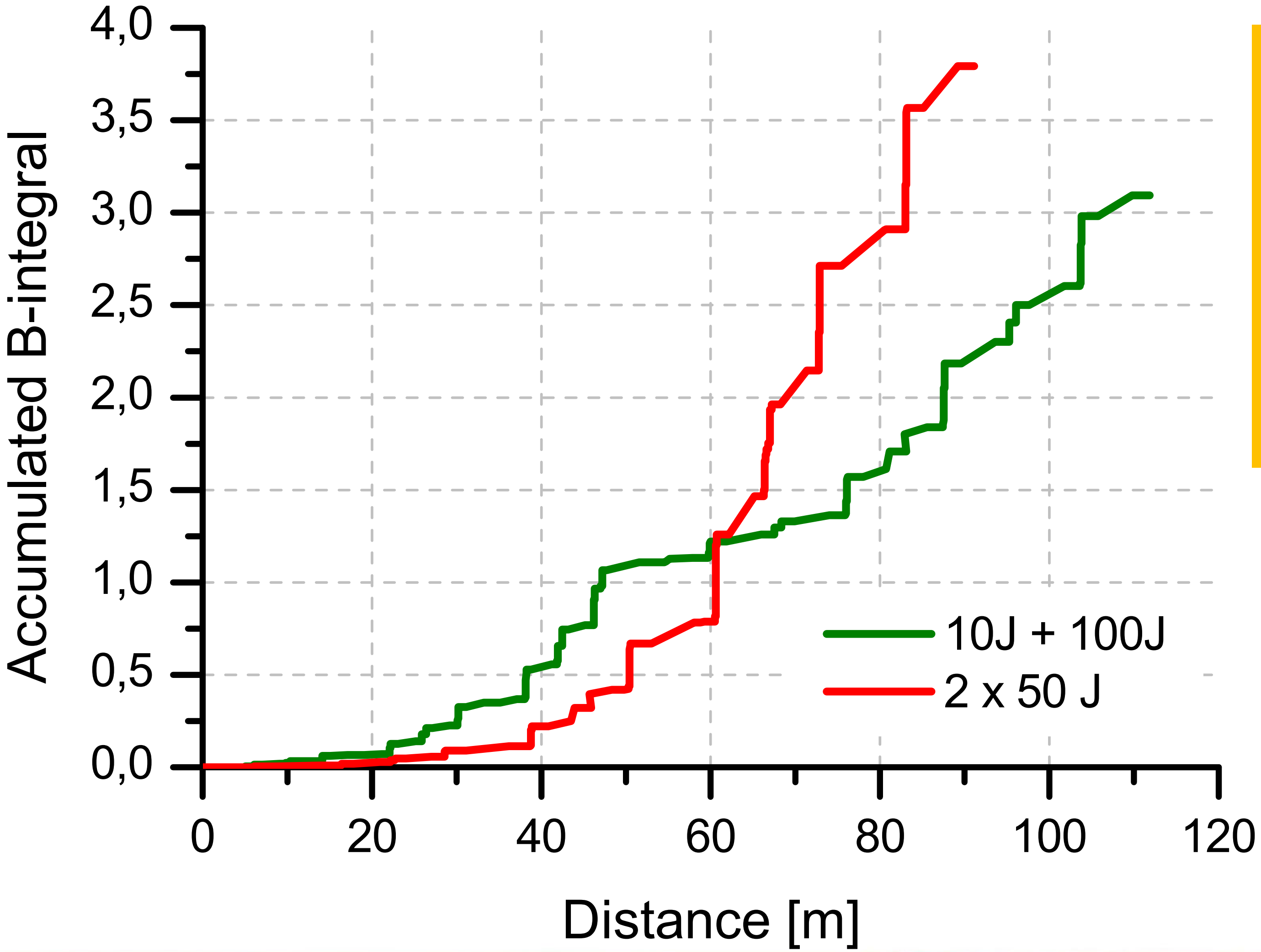
Included:

- **Wavefronts from optical surfaces**
- **Pinholes**
- **Angular multiplexing**

Next:

- **Deformable mirror**

Accumulated B-integral in 100 J laser systems



Not included yet for both schemes:

- **Wavefronts from optical surfaces**
- **Pinholes**
- **Angular multiplexing**
- **Deformable mirror**

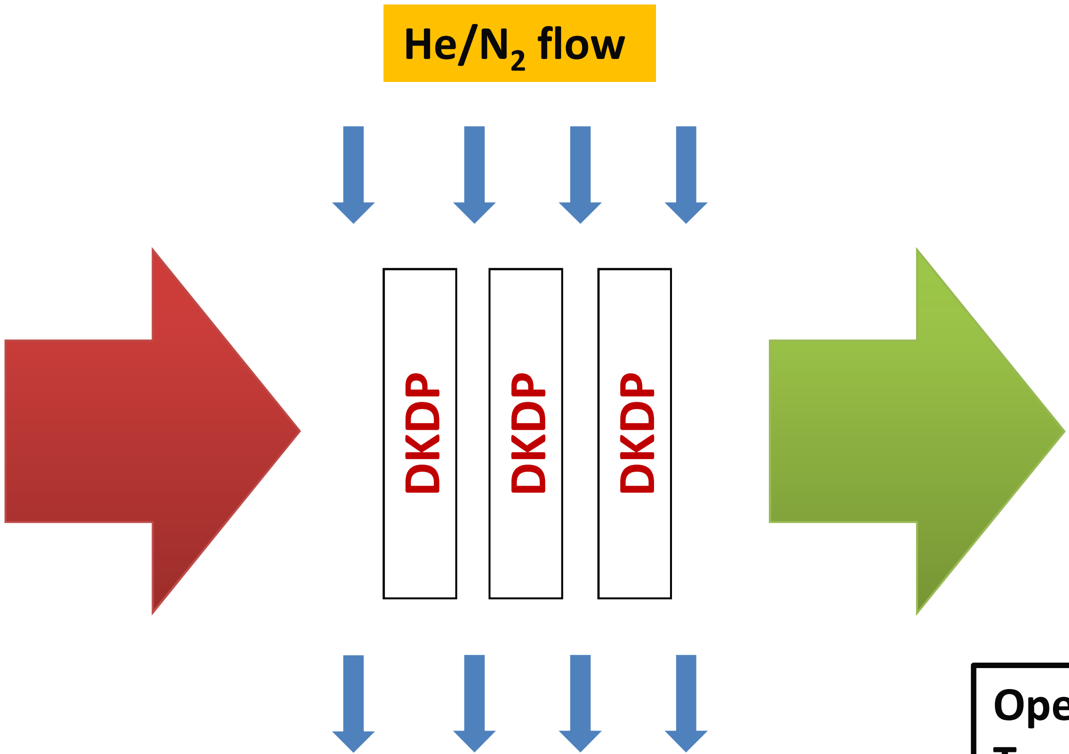
Summary of specifications for 100 J laser

	10 J + 100 J	2 * 50 J
Slab size [mm^3]	20x20x5 + 60x60x8	45x45x7
Volume [cm^3]	238.4	226.8
E_p [J]	477	410
F_{peak} [J/cm^2]*	**8.9**	9.2
Eout [J]**	107	104
Efficiency (o-o)	22.5 %	25.0 %
B_{acc}	**3.1**	3.8
N. optical components***	3+3 SF, 3 PC, 4+2 P	3 SF, 1 PC, 2 P

* Last pass at MSF (Multipass Spatial Filter)
** Flat top shape
*** SF = Spatial filter ; PC = Pockels Cell ; P = Polarizer

Wavefronts, Pinholes, Angular multiplexing, Deformable mirror will be included

SHG optimization with DKDP crystals



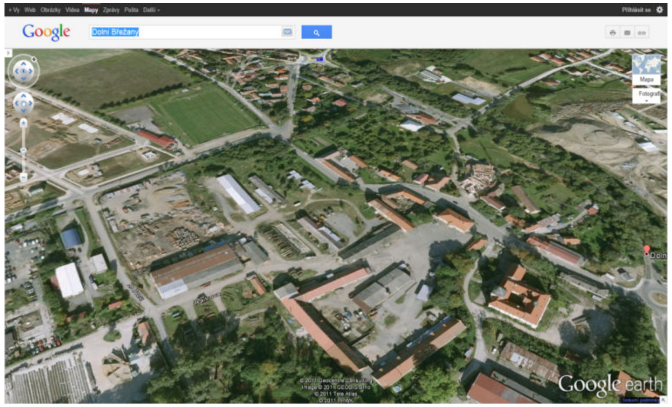
Evaluation of the feasibility of He/N2 gas flow is in progress

Operating temperature	303 K
Temperature homogeneity	1 K
Volumetric heat	0.125 W/cm^3
Number of slabs	1-3
Total thickness	30 mm

HiLASE project timeline

09/2011	*Project start*		
10/2012 – 3/2014	*Construction of new building*		
Q2/2014	*Relocation from Prague*		
2011 – 2014	*Research, development & installation of the laser systems*		
	Milestone 1:	1-10 J, 10 Hz, 2-3 ns, 160 K	**2013**
	Milestone 2:	100 J, 10 Hz, 2-3 ns, 160 K	**2014**
Q2/2015	*Commissioning*		
09/2015	***Operational phase***		

HiLASE will be located south of Prague



26 km from IoP Prague
20 km from Prague Int. Airport

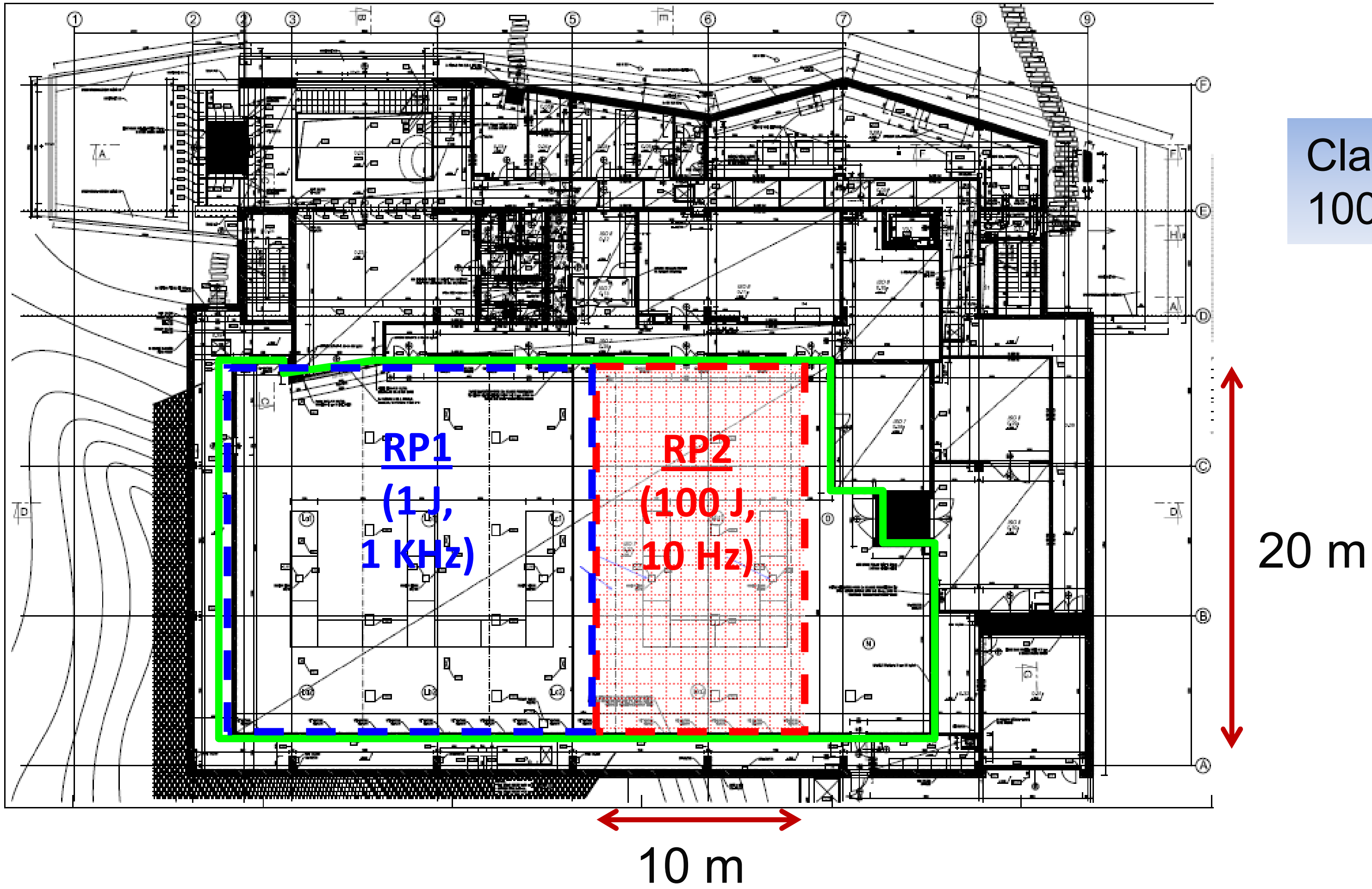
Construction will start in October 2012

PREPARATORY CONSTRUCTION WORK HAS STARTED IN JAN. 2012

AUG. 2012

Site area for HiLASE facility - <u>8 535 m²</u>

HiLASE laboratory



Class 10,000 for
100 J laser system

Acknowledgments

HiLASE

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ELI

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Jakub Novak
M. Koselja
M. Fibrich

CEA-Grenoble

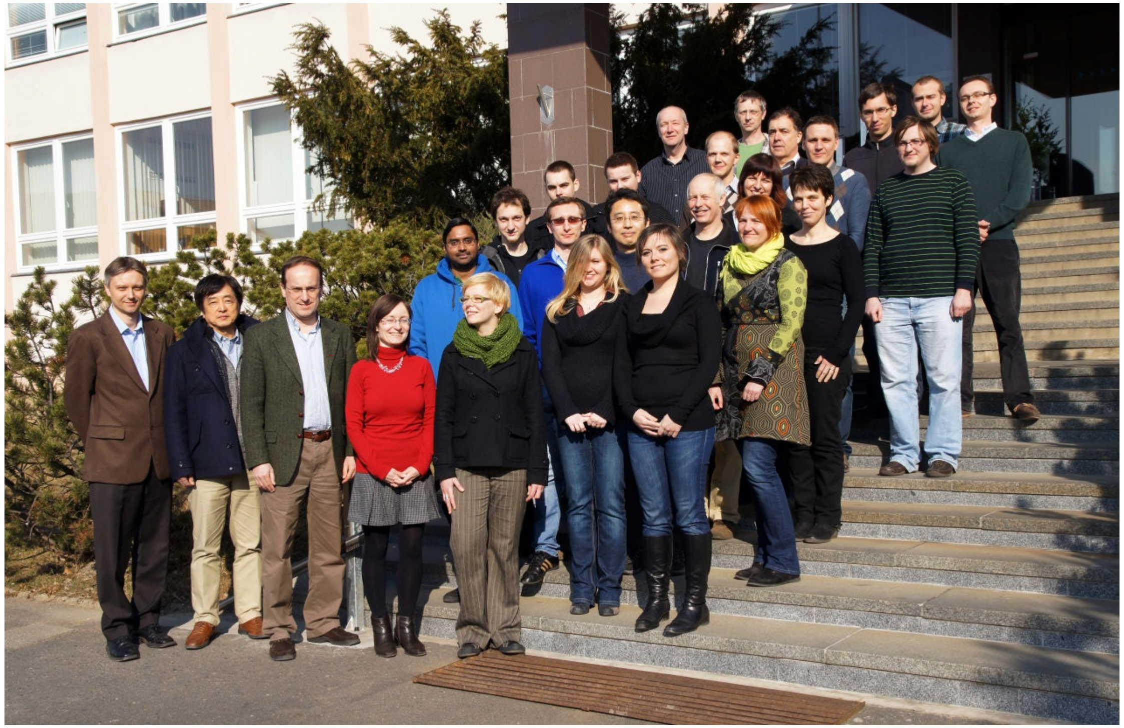
J.P. Perin

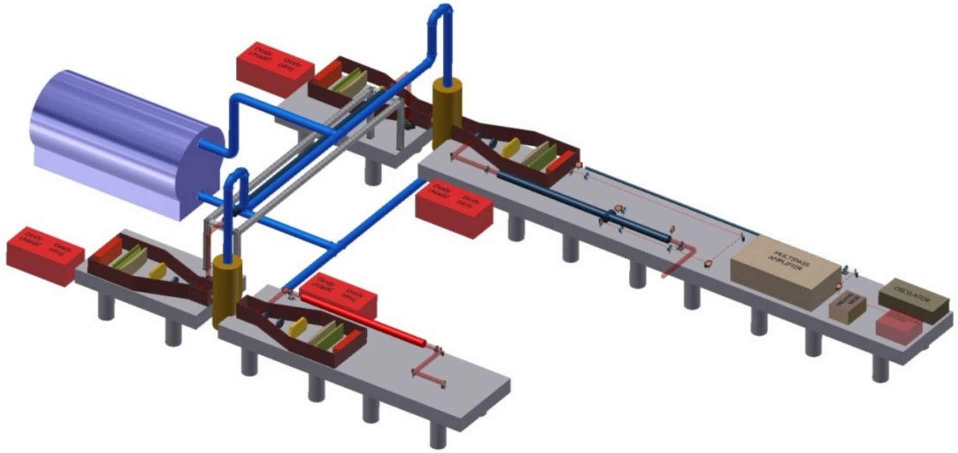
HZDR

M. Siebold

IOQ-Jena

J. Hein
J. Koerner
G. Paulus





Thank you for your attention

Summary of specifications for 100 J laser

	Epump [J]	Eout [J]	Effic [%]	Fpeak (on element) [J/cm2]	Fpeak (in air) [J/cm2]	Fpeak (in element vs dist.) [J/cm2]	Fpeak* (on reverser mirror) [J/cm2]	Acc B-integral [rad]
10J + 100J without wavefrotns, without pinholes, without angular multiplexing flat pump	40 + 437	107	22.5	8.9 (last pass, input MSF)	8.9	28 (ejection mirror in MSF)	6.7	3.1
2 x 50 J without wavefronts, without pinholes, without angular multiplexing flat pump	410	104	25.0	9.2 (last pass, input MSF)	9.2	10 (ejection mirror in MSF)	3.34	3.8
2 x 50 J with wavefronts, with pinholes, with angular multiplexing supergauss pump	400	105.5	26.3	13.5 (last pass, input MSF)	13.5	26 (ejection mirror in MSF)	4.5	3.8

*possible location of Pockels cell, can be decreased at the cost of beam size